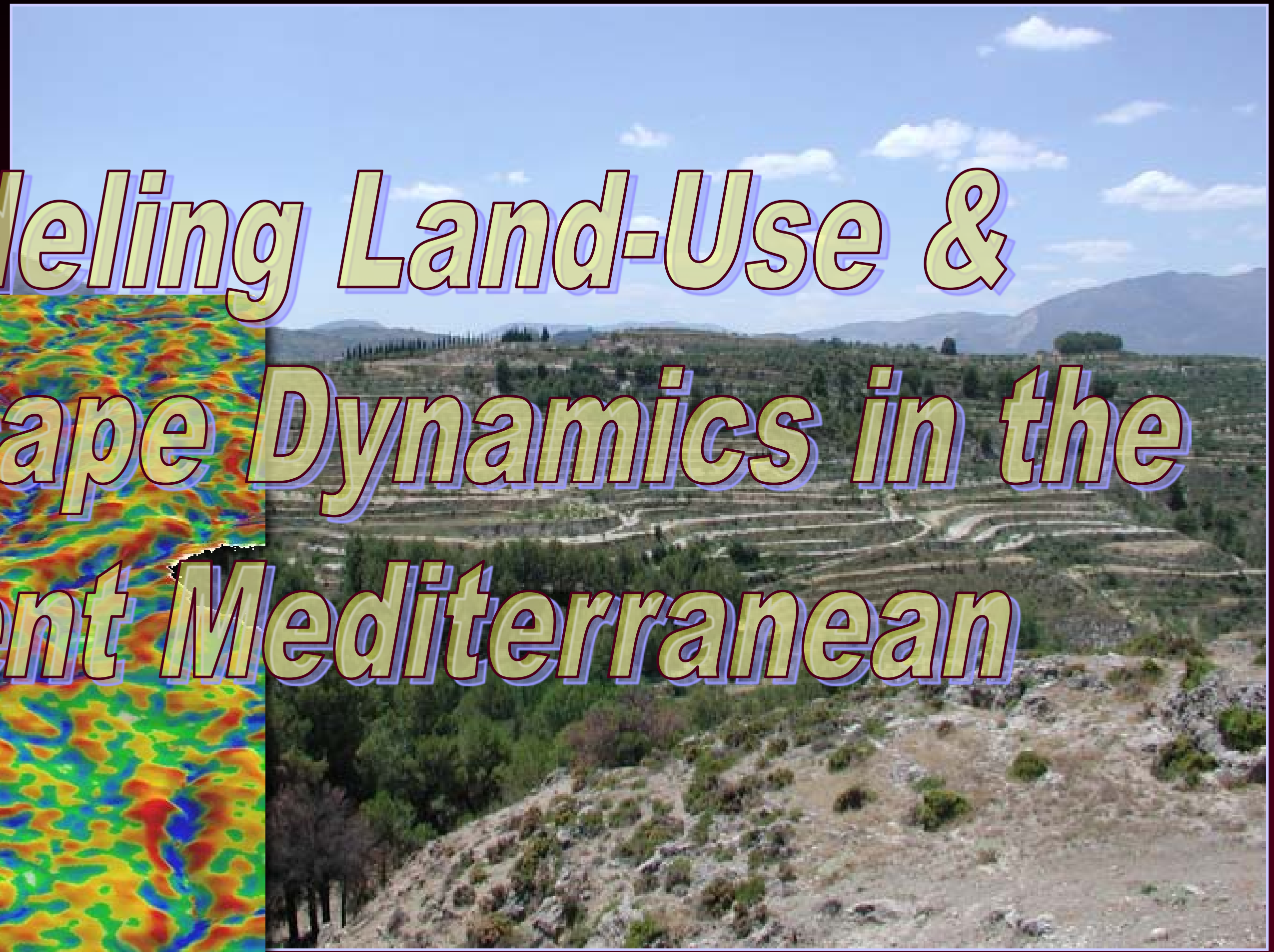
Modeling Land-Use & Landscape Dynamics in the Ancient Mediterranean



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Mediterranean Landscape Dynamics

- **Importance of project is not agent-based modeling *per se***
- **But the integration of ABM with other kinds of dynamic modeling**
  - **Landscape**
  - **Climate**
  - **Vegetation**
- **Will focus especially on this integration**

MedLand Modeling Laboratory

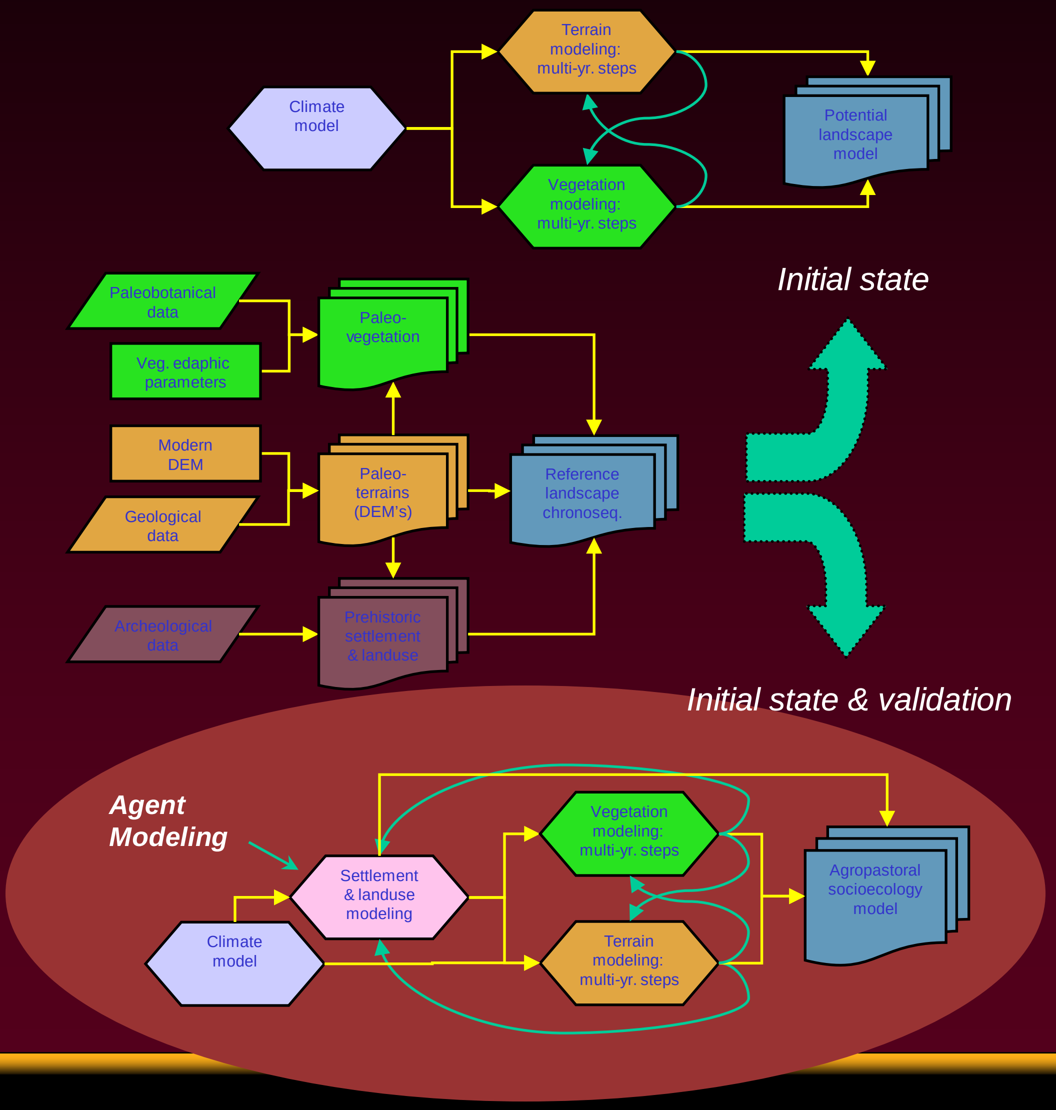
- Dynamically coupled models
  - ABM:
    - Agents (individuals, households, villages)
    - Behaviors based on decision rules and environmental information
    - Object oriented programming
  - Landscape cellular automata
    - Surface processes of erosion/deposition
    - Dynamics derived from differential equations
    - Hybrid object-oriented and procedural language programming

MedLand Modeling Laboratory

- Models for parameterization
  - Climate: geospatial model
    - Values for each climate station
    - Estimated values between climate stations
    - Based on multiple regression
  - Vegetation: geospatial model
    - Estimated values based on topography and climate
    - Based on multiple regression
  - Soils: geospatial model
    - Currently simple algebraic derivation

MedLand Modeling Laboratory

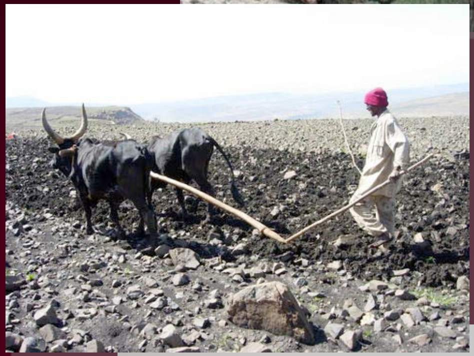
- 3 interlinked modeling environments
  - Potential landscape model
  - Reference landscape chronosequence
  - Agropastoral socioecology model



Agent Based Model

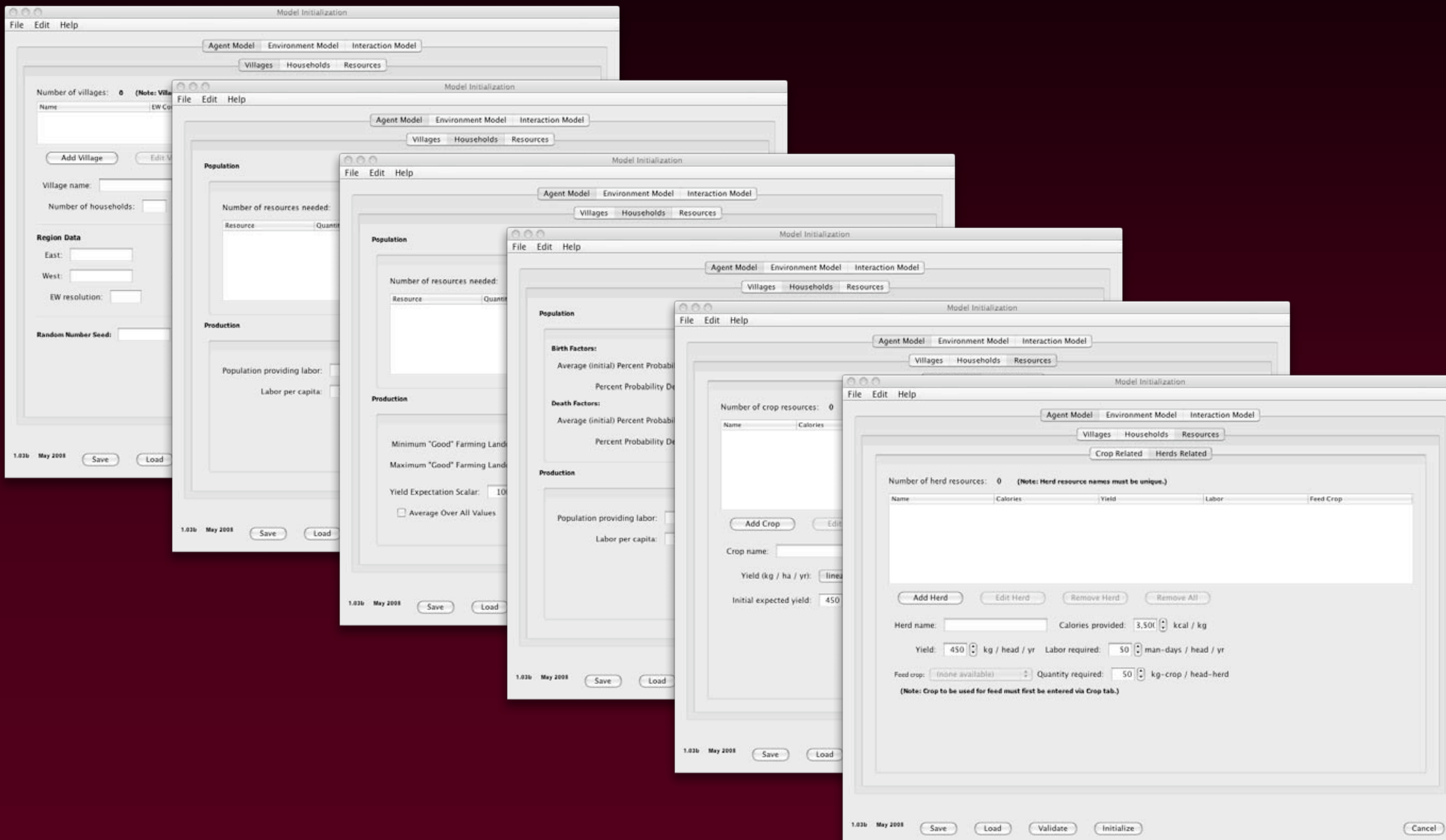
- DEVSJAVA
  - Discrete Event Simulation
  - Internal model formalisms help to improve validation of model operation
- Interaction model
  - Separate model
  - Explicitly handles links between ABM and surface process model

Agent Based Model

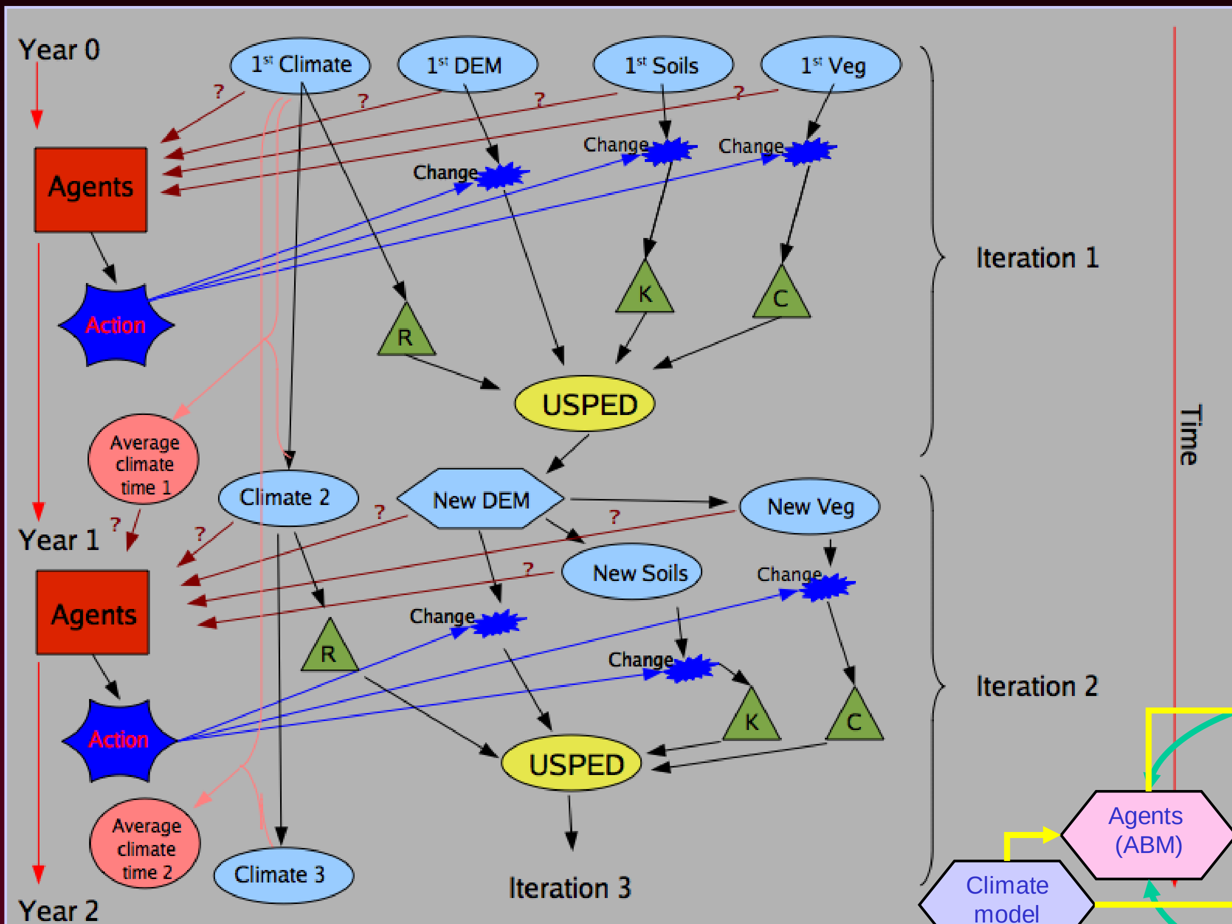


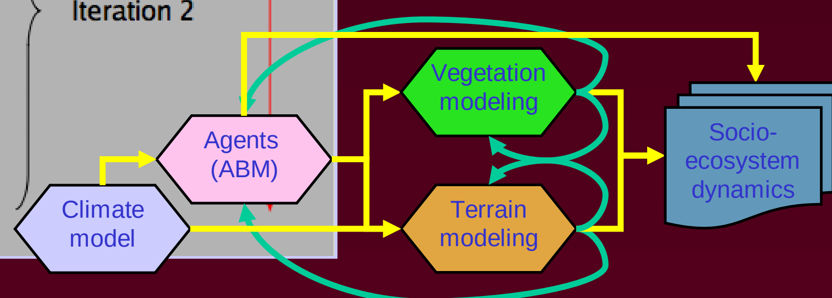
- Household is basic unit (agent)
- Landuse decisions (GIS→ABM)
  - Potential productivity
  - Distance from village
  - Labor investment needed (e.g., clear land or simply cultivate)
- Landuse activities (ABM→GIS)
  - Clearing land
  - Cultivating crops for consumption or foddering
  - Fallowing
  - Harvesting crops
- Returns (GIS→ABM)

Agent Based Model



Hybrid ABM & Landscape Model



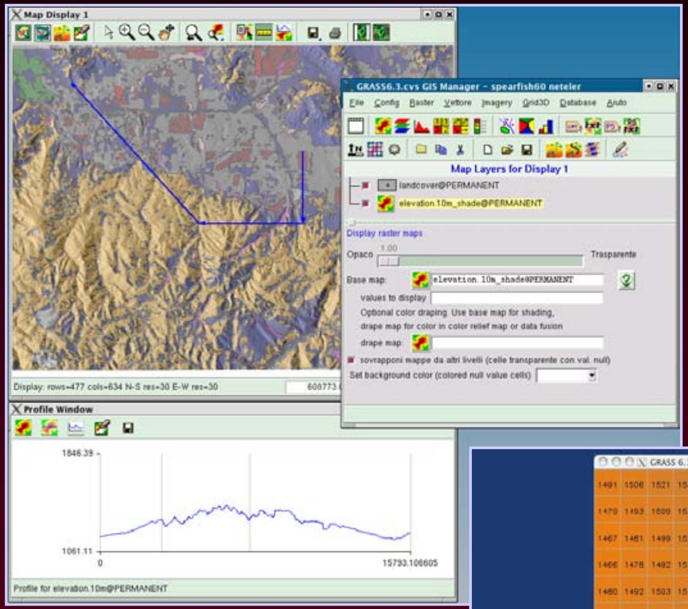


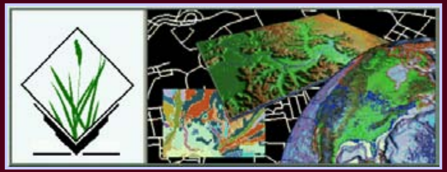
Surface Process Dynamics

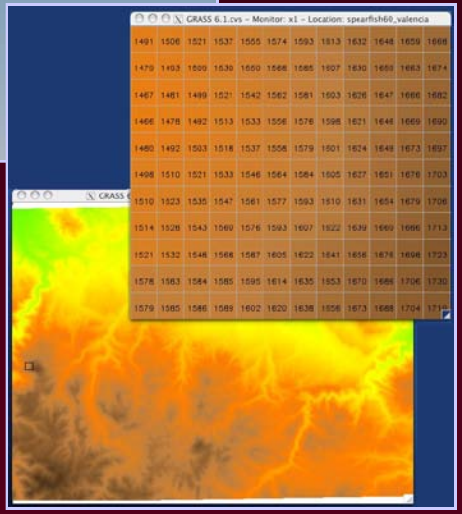
- **USPED (Unit Stream Power Erosion/ Deposition)**
  - Well-known model for landscape change
  - Iterated to simulate cumulative change
- **Model parameters**
  - Landuse/Landcover
  - Topography
  - Climate
  - Soil

Surface Process Model

- **Modeling environment built in GRASS**
  - Open source GIS, anaysis, and modeling environment
  - Raster (cellular) landscape

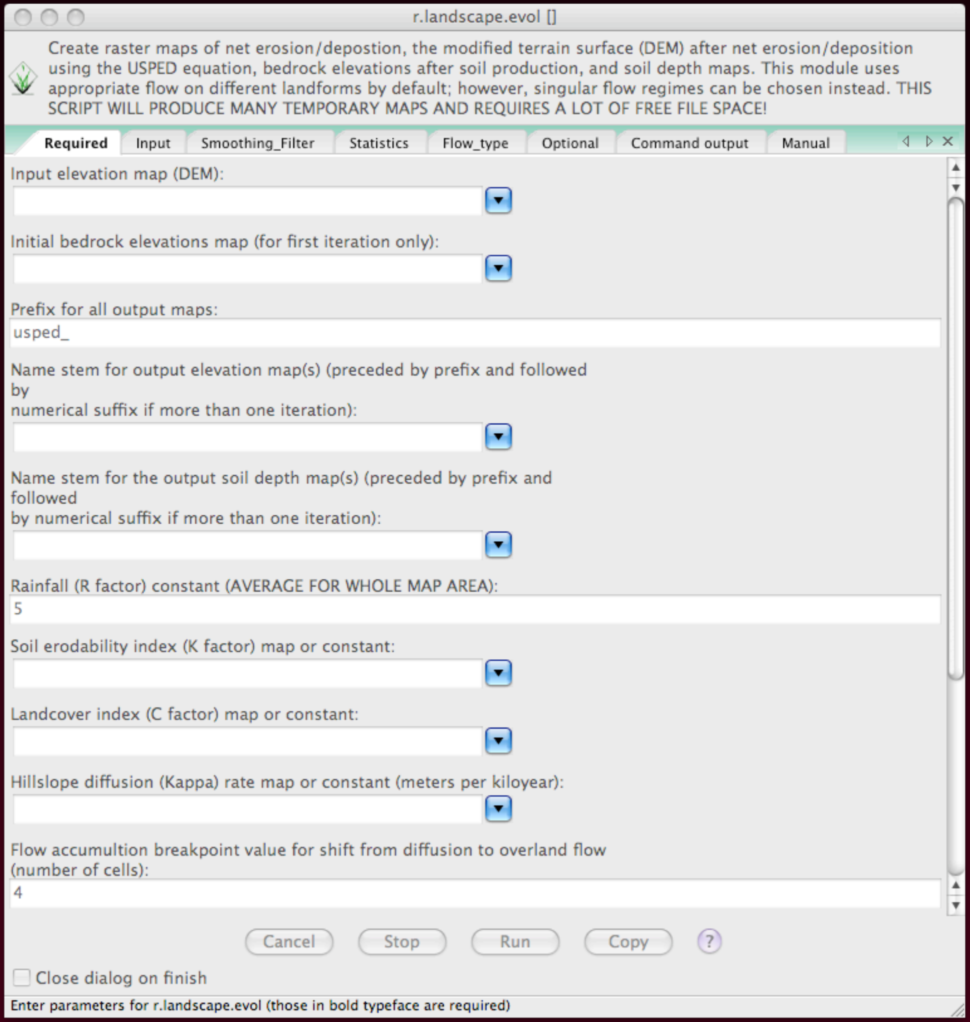






Surface Process Model

- **Scripting in GRASS**
  - **Can use many different programming or scripting languages to chain together GRASS commands**
  - **Initially using BASH shell script**
  - **Switching to Python**



Surface Process Model

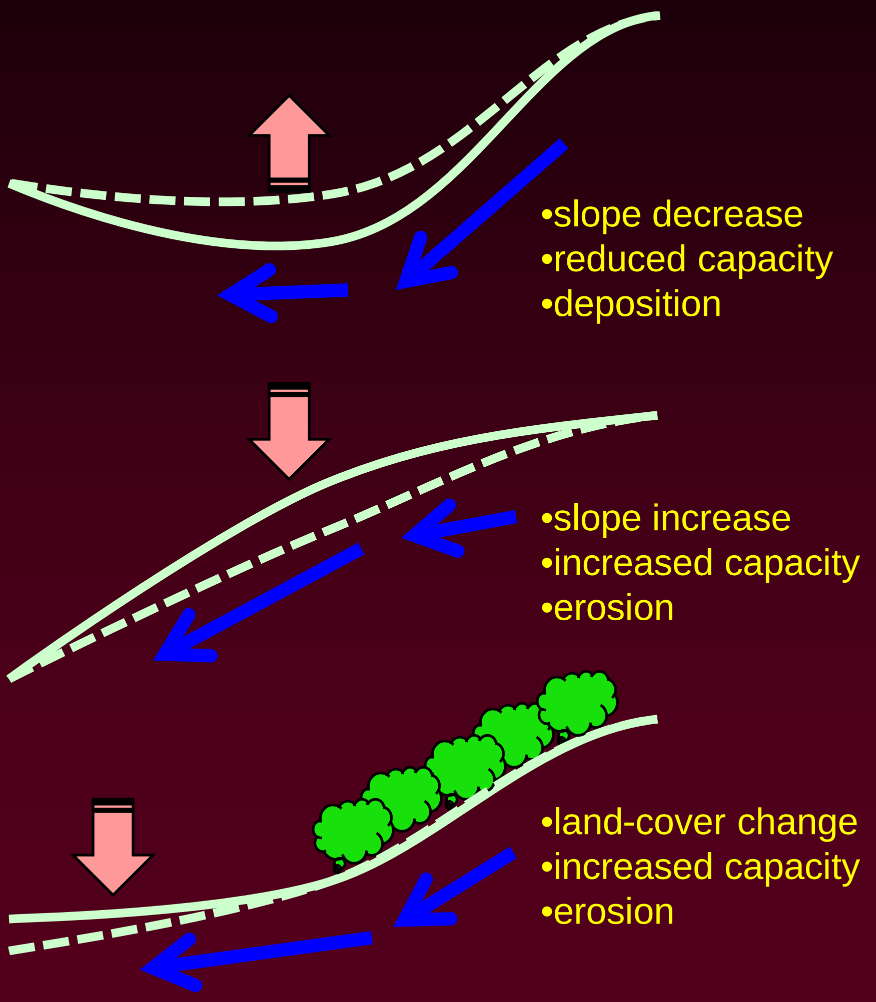
- USPED (as implemented in GRASS)
  - ED = d(Ep · qsx)/dx + d(Ep · qsy)/dy
  - ED is net potential erosion or deposition of sediment in any landscape cell
  - qsx and qsy are the sediment transport capacity coefficients in x and y directions (a function of slope, aspect, and flow accumulation) for a given surface process across the cell
  - Ep (potential erodability) is modified a RUSLE value that includes for each cell…
    - rainfall intensity
    - land cover
    - soil characteristics

Surface Process Model

- **Sediment transport capacity**
  - Slope and aspect from r.slope.aspect
  - Flow accumulation from r.terraflow (direct accumulation value) or r.flow (length-slope factor)
- **Potential erodability**
  - Rainfall intensity as R-factor
  - Land cover as C-factor
  - Soil characteristics as K-factor
  - Can use constants or maps (i.e., can vary for each cell)

Surface Process Model

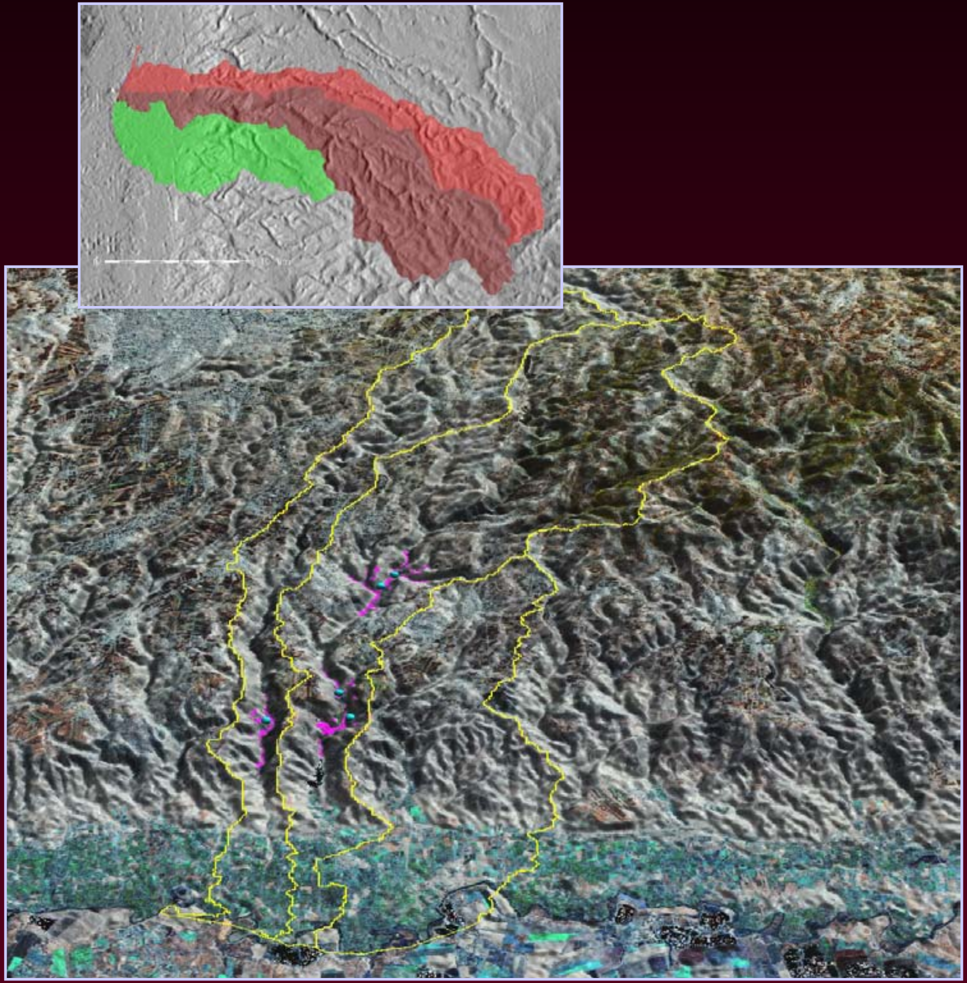
- **Basic assumption**
  - flowing water carries sediment at capacity
- **Dynamics**
  - Changes to hydrology affect transport capacity
  - Water will erode or deposit sediment until its load reaches its new capacity



Surface Process Model

- Input parameters
  - Topography (map – initial and from prior iteration)
  - Land cover (map or constant – from ABM)
  - Rainfall (constant for watershed)
  - Soil erodability (map or constant)
  - Bedrock topography (map)
  - Number of iterations (if not using ABM)
- Output
  - Net erosion (map)
  - Topography (map – for next iteration)

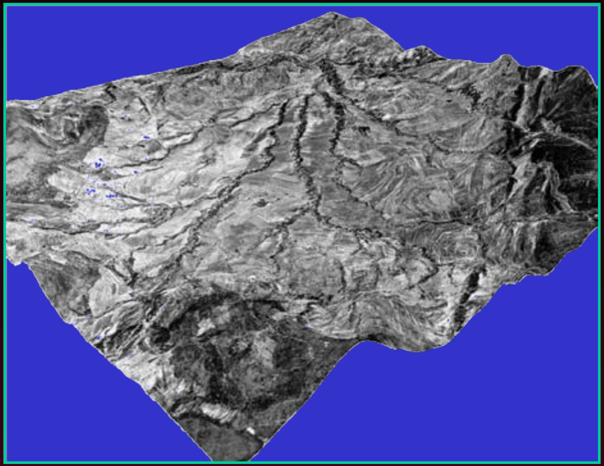
Model Components: Topography

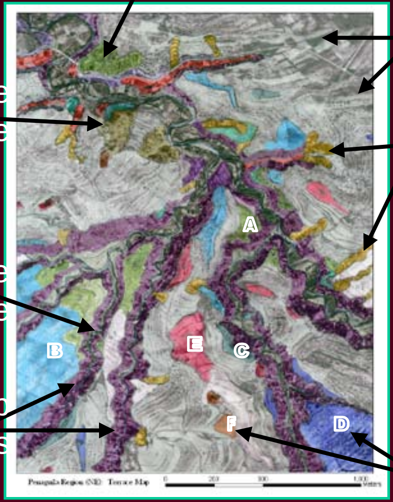


- Terra ASTER DEMs (30m)
  - Re-interpolated to 15m resolution for surface process modeling
- High resolution DEMs (1m) from stereo aerial photos
- Study areas defined as watersheds

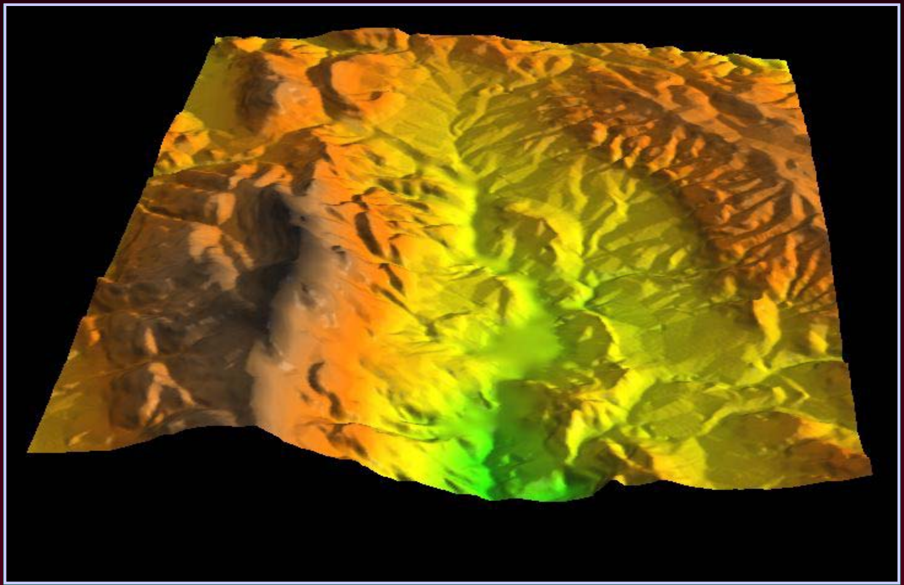
Model Components: Topography

- High-resolution DEM created from stereo aerial photos
- Landform and geomorphic mapping with ground truthing in field
- For paleolandscape reconstruction and verification





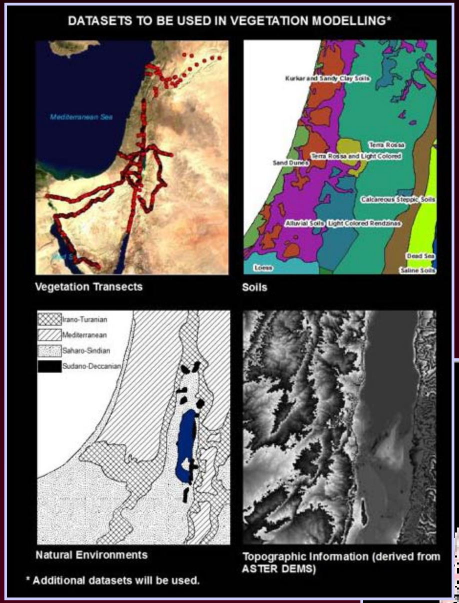
Model Components: Topography

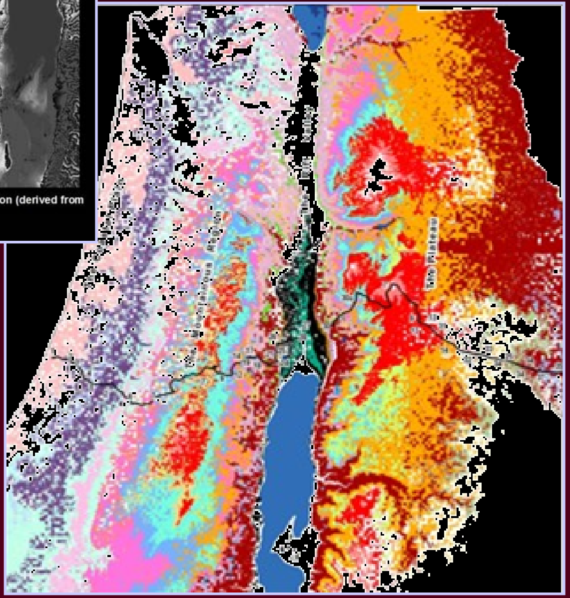


- Paleolandscape reconstruction
- ID paleosurface remnants
- Connect (or remove) equivalent aged surface remnants using GIS interpolation

Model Components: Vegetation

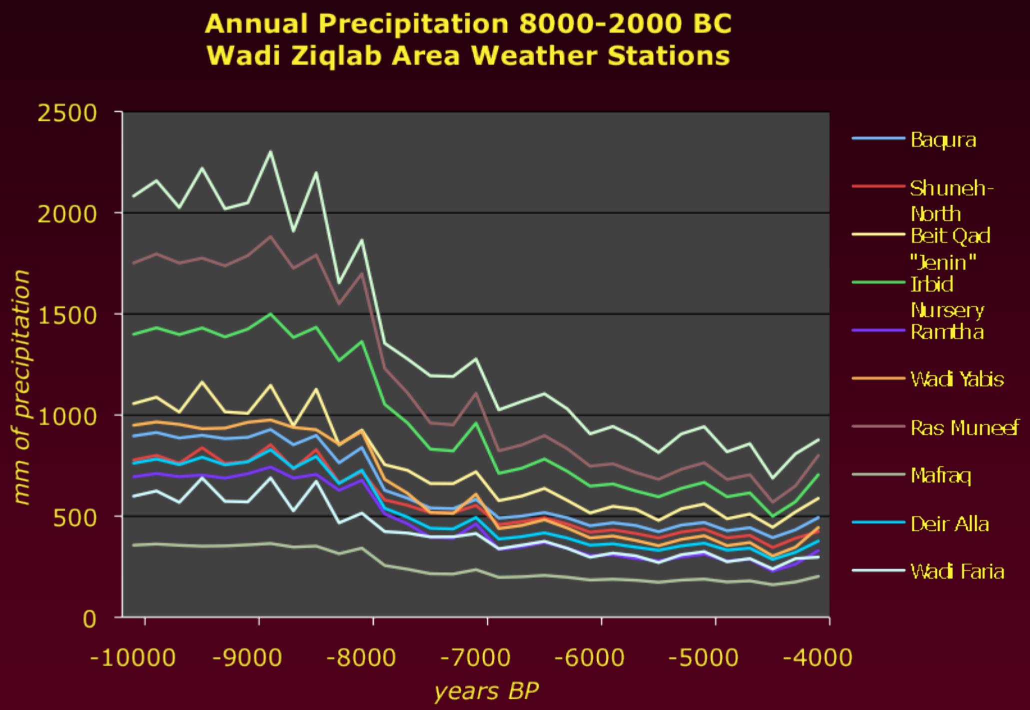
- **Community models based on**
  - climate
  - topography
  - soils
  - vegetation transects
- **Successional dynamics**





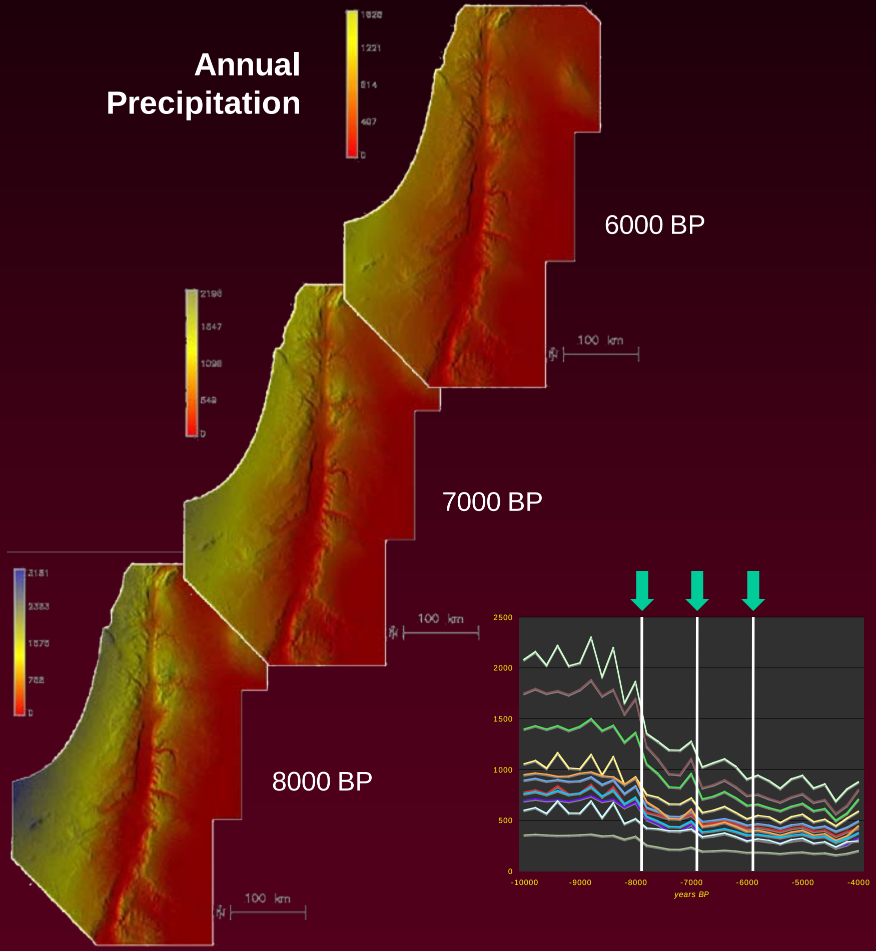
Model Components: Climate

- **Weather station data retrodicted for 40ky at 100yr intervals to produce sequences for…**
  - annual and monthly precipitation
  - annual and monthly mean temperature
  - annual and monthly days>40° & days <0
  - annual and monthly storm frequency



Model Components: Climate

- **Models**
  - Created at weather stations
  - Transformed into paleoclimate landscapes using multiple regression
- **Temperature**
  - Topograpy
  - Latitude
  - Longitude
- **Precipitation more complicated. Also uses…**
  - Distance from sea
  - Orographic features between station and sea.
- **Regression coefficients applied to DEMs in GRASS to generate *climate surfaces***



Model Components: Soils

- Initialize as constant thickness
- Calculate K-Factor from sand:silt:clay ratios or bedrock geology
- Dynamically model changing soil thickness and erodability
- Remantle paleosurfaces with Holocene soils.

Experiments in Landuse Dynamics

- **Experimental design**
  - **Control (no agropastoral landuse)**
  - **Vary…**
    - **Population size**
    - **Agripastoral strategies**
    - **Climate**
    - **Lengths of time**
  - **Dynamic system modeling (i.e. without ABM)**
    - **Agropastoral catchments *grown* outward from settlement**
    - **Stochastic algorithm to distribute landuse activity each year**

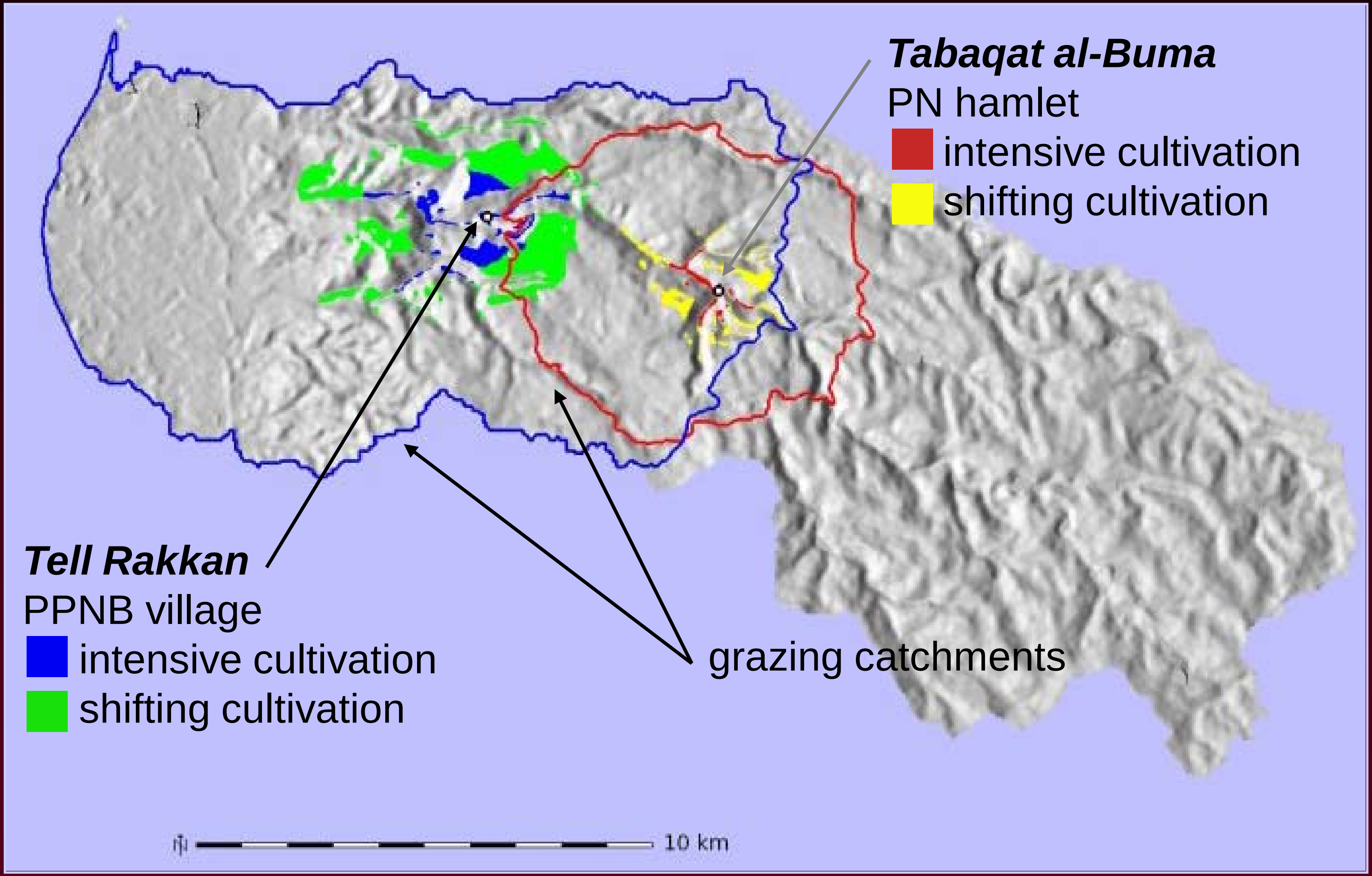
Experiments in Landuse Dynamics

- 2 climate regimes
  - *r = 6.69 (PPNB at 8,000 BP)*
  - *r = 5.26 (PN at 7,500 BP)*
- 2 Neolithic scenarios
  - PPNB village (wetter)
  - PN hamlet (drier)
- 2 agricultural strategies
  - Intensive cultivation
    - Base agricultural catchment calculated from settlement size
  - Shifting cultivation
    - Catchment 5x size needed (= 5yr fallow cycle)
    - Randomly seed 20% as cultivated each year

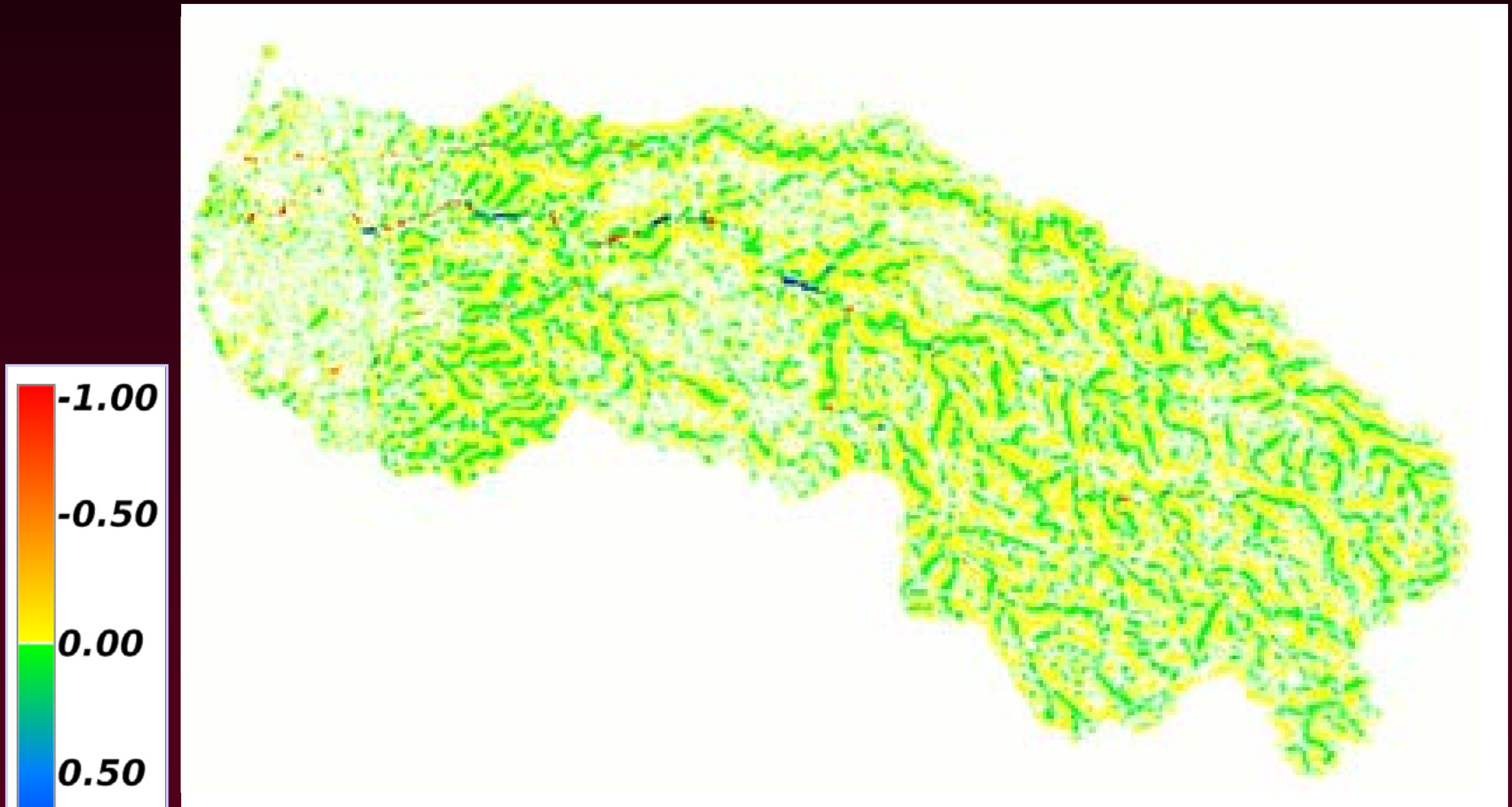
Experiments in Landuse Dynamics

- Extensive pastoralism
  - Catchment 5x size needed
  - Randomly seed 20% as grazed each year
- Simple revegetation/succession
  - Allow formerly cultivated (or grazed) patches to return to the land-protection equivalent of woodland when not cultivated or grazed for 50 years
- Run experiments
  - Two generations (40 years)
  - Ten generations (200 years)

Experiments in Landuse Dynamics

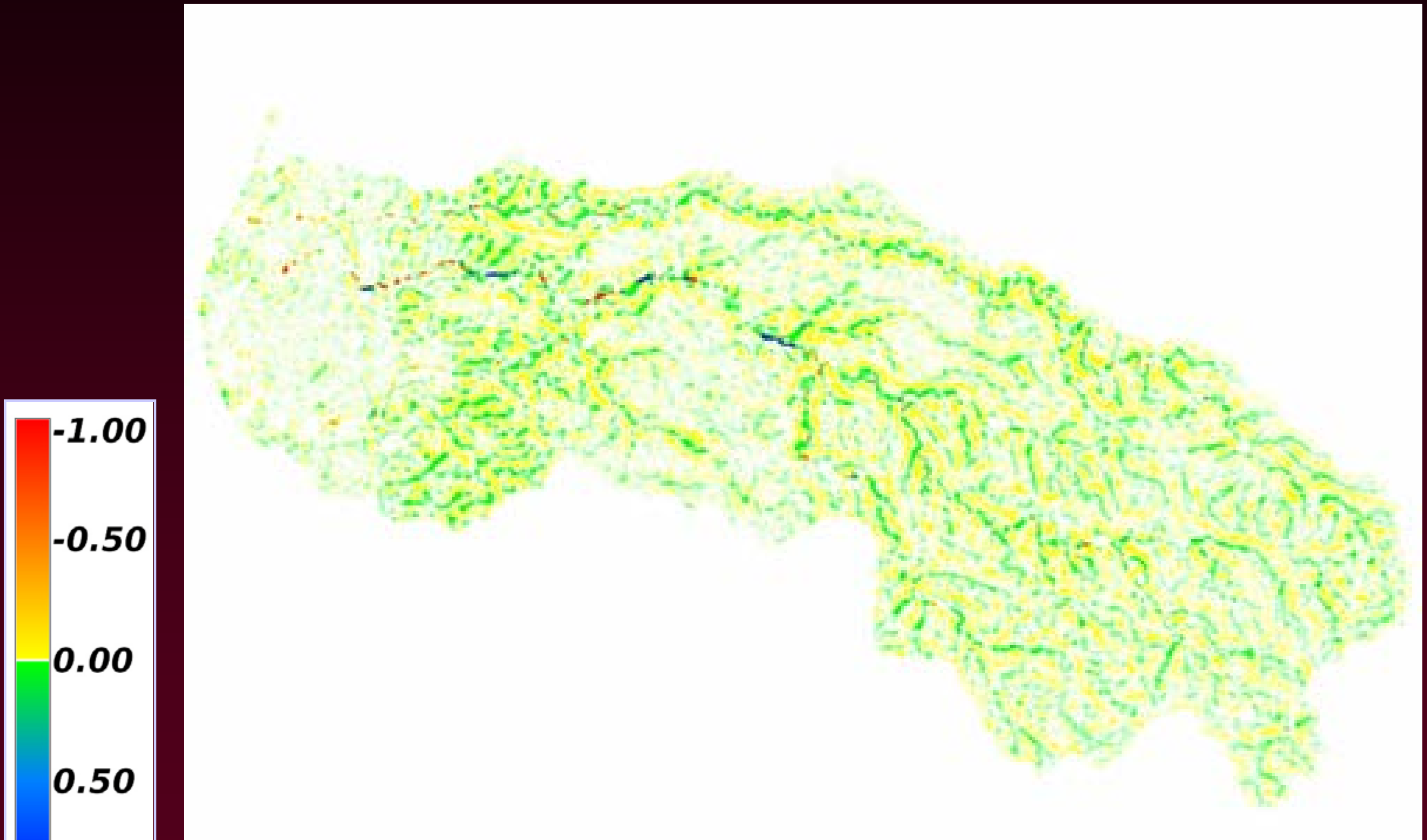


Experiments in Landuse Dynamics



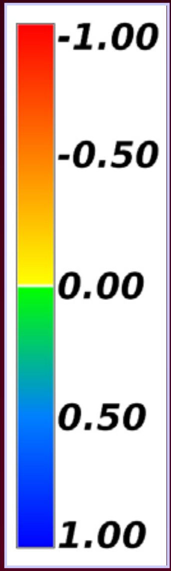
Control: low rainfall, no agripastoral landuse (potential landscape model)

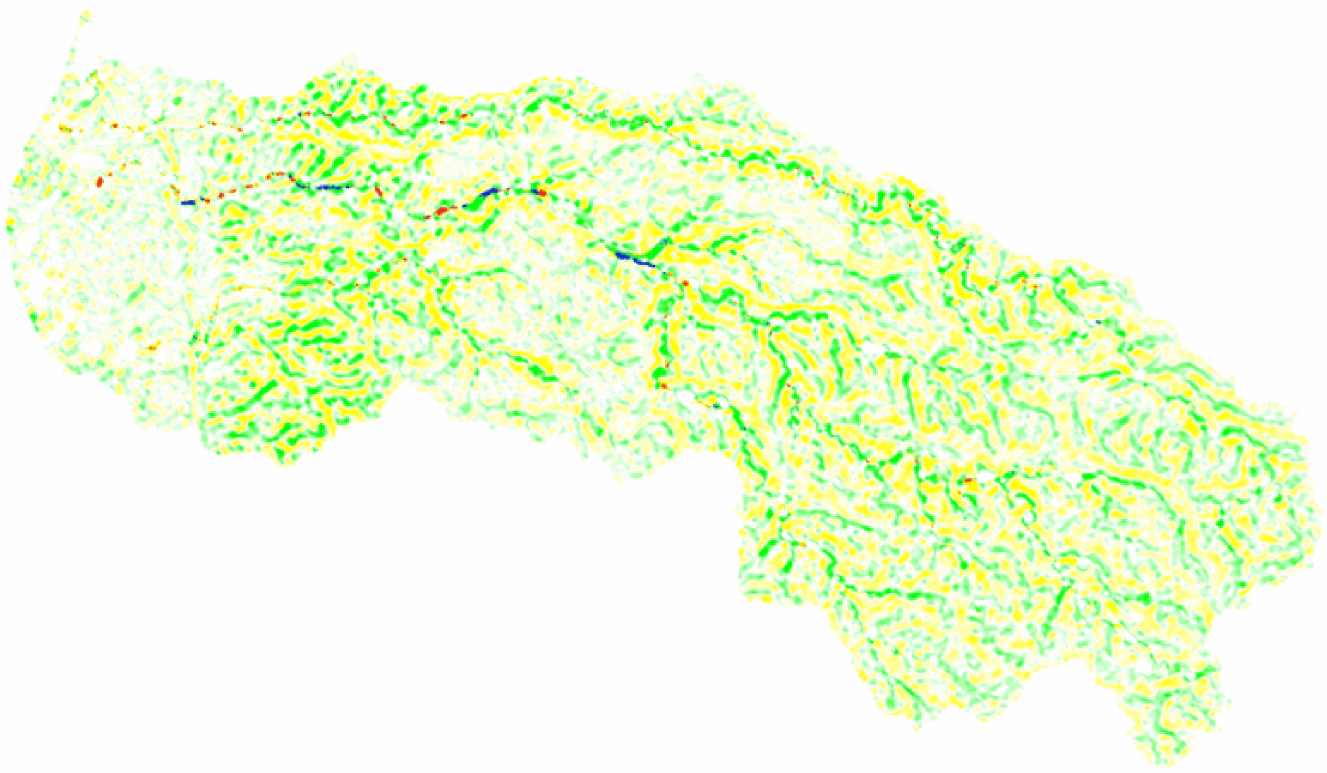
Experiments in Landuse Dynamics



Tabaqat al-Buma: PN, low rainfall, intensive agriculture, grazing

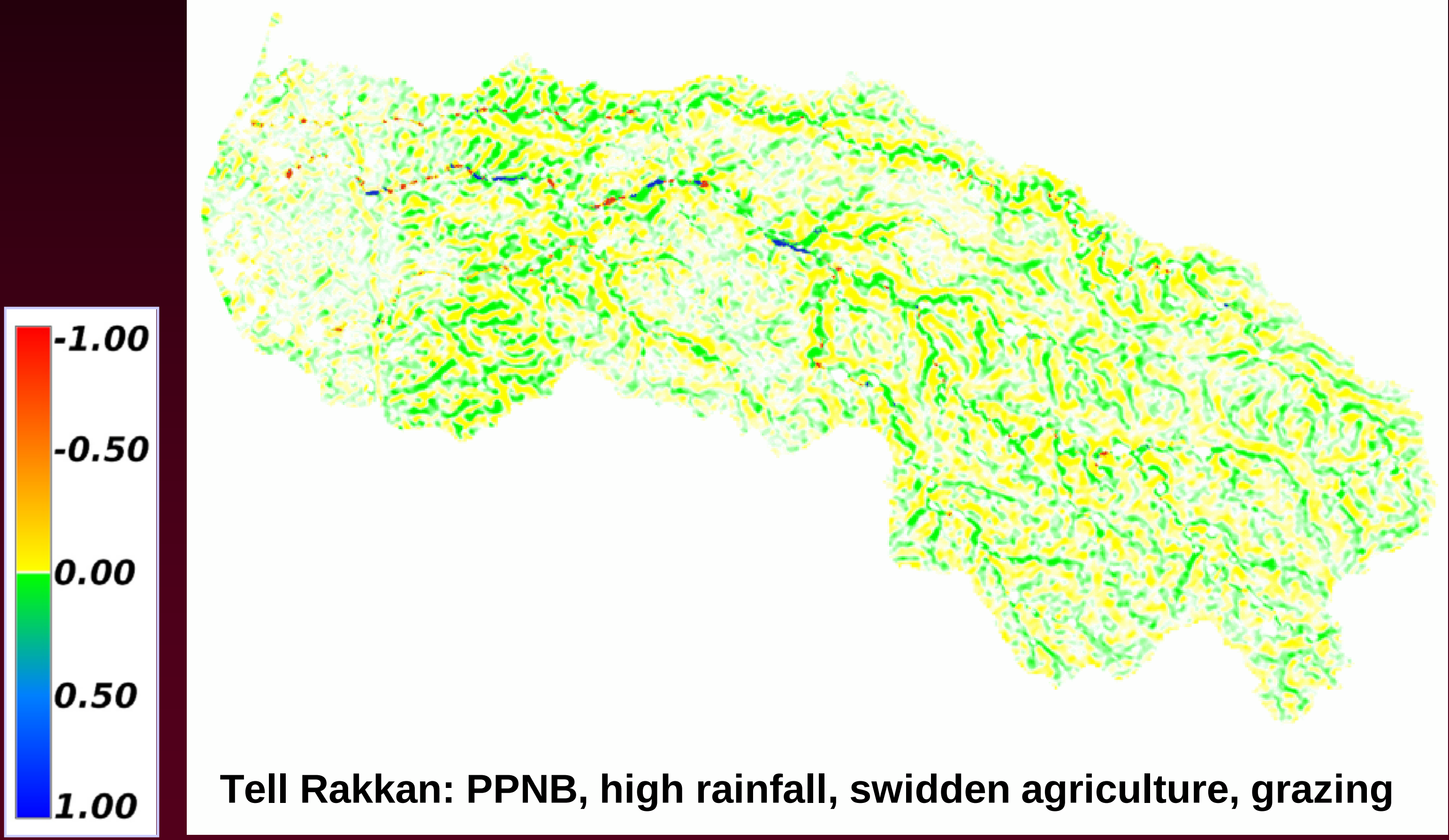
Experiments in Landuse Dynamics





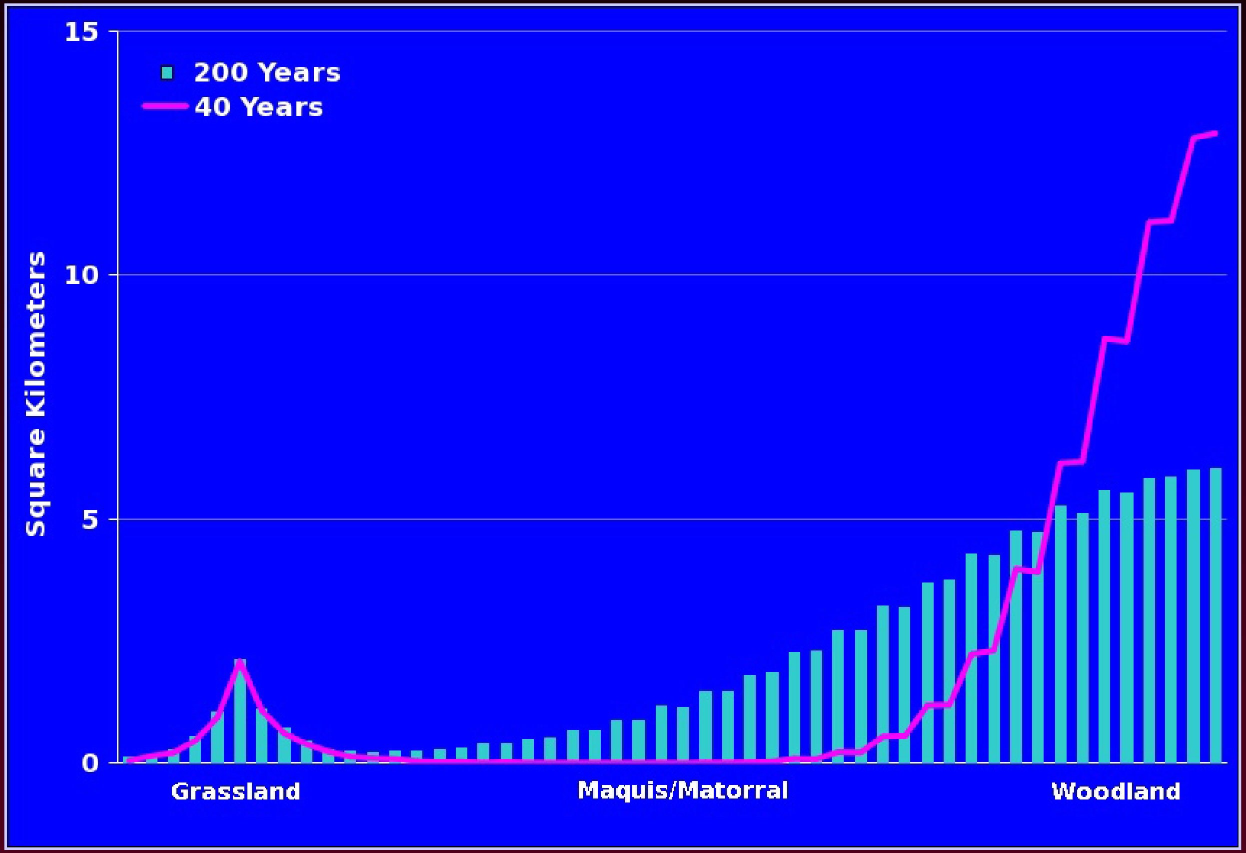
Tabaqat al-Buma: PN, low rainfall, swidden agriculture, grazing

Experiments in Landuse Dynamics



Tell Rakkan: PPNB, high rainfall, swidden agriculture, grazing

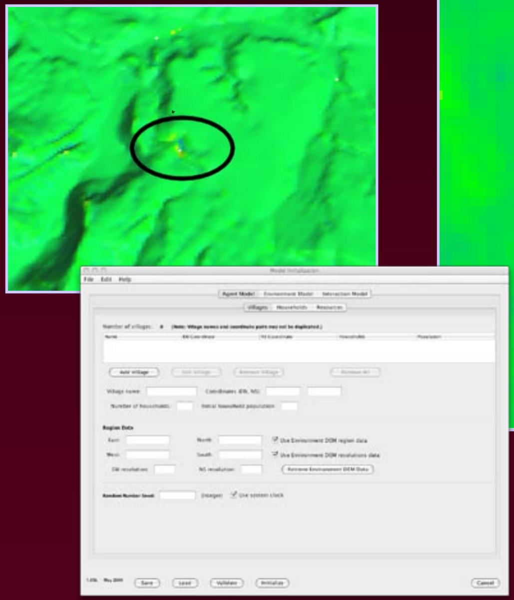
Experiments in Landuse Dynamics

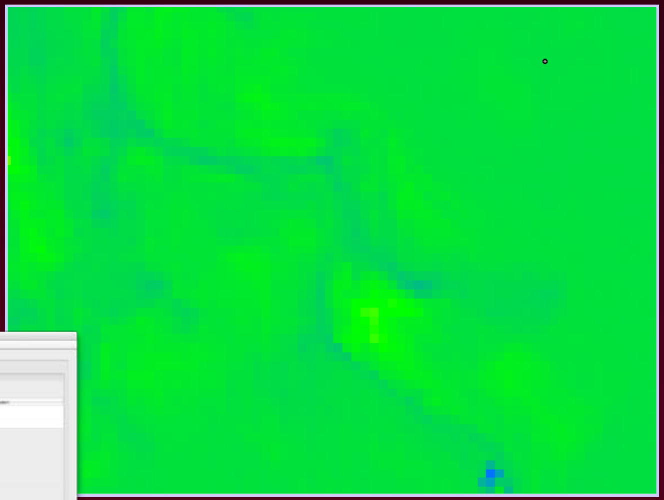


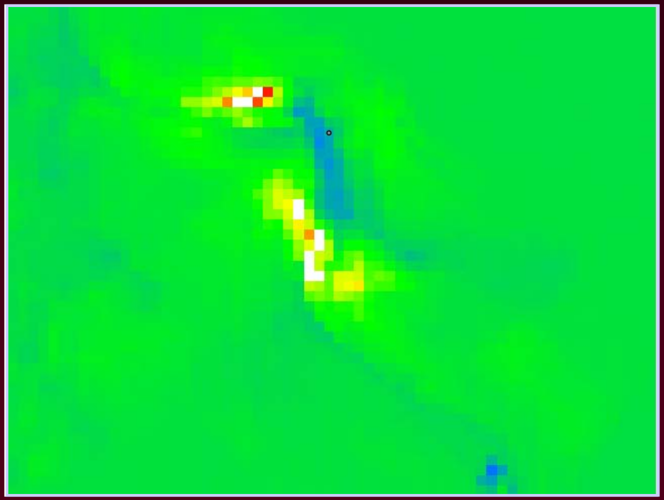
Tell Rakkan: PPNB, high rainfall, vegetation change, 40 yrs vs 200 yrs (swidden agriculture, grazing)

Hybrid ABM & Landscape Model

- Multiagent simulation (DEVSJAVA) coupled with GIS (GRASS)
- Impacts of 65 years of farming on soil depth

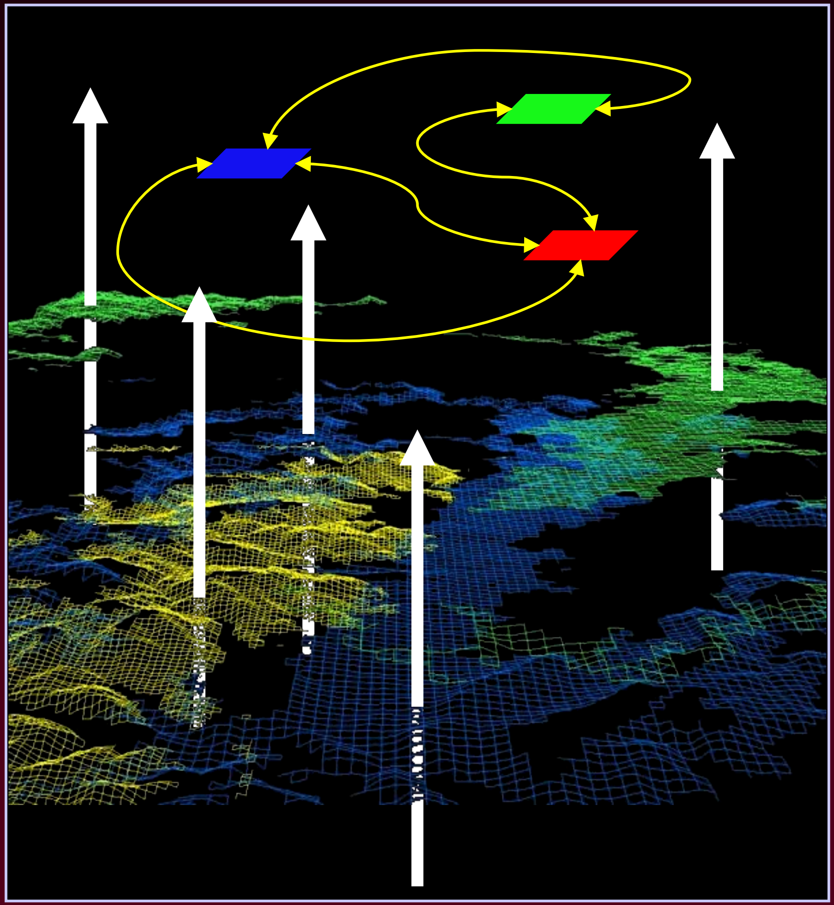






cleared
cultivated
village

Models and Archaeology



- **Archaeological record**
  - rigorous test-bed for evaluating models of social dynamic
  - Models must pass through known *sparse points* of discontinuous record , scattered through time and space.
- **Increases model robusticity for application in other times and places**

Access

- Model availability
  - GRASS addons site (now): http://svn.osgeo.org/grass/grass-addons/LandDyn/
  - Open ABM Consortium (soon): http://www.openabm.org
- GRASS
  - http://grass.osgeo.org
- Policy applications
  - ASU Decision Theater (completing development):
  - http://serv.asu.edu/temp/Michael_Barton/2008_04_15/
  - http://www.decisiontheater.org/

Interdisciplinary Collaboration

- **ASU**: School of Human Evolution and Social Change, Center for Social Dynamics & Complexity, School of Earth and Space Exploration, School of Computing and Informatics, Geographical Sciences, School of Sustainability
- **Partners**: Universitat de València, Universidad de Murcia, University of Jordan, North Carolina State University, University of Wisconsin, Hendrix College, Geoarchaeological Research Associates, GRASS GIS Development Team

The Past as Key to the Future